Significant Ongoing and Emerging Issues

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Section 11: Significant Ongoing and Emerging Issues

11.1 Introduction

This section provides some insight into the issues that will be important for the Lake Erie LaMP to address now and report on in the LaMP 2002 Report. Some of these issues are ongoing, and much research and policy discussion has already been applied to management decision making. Others are setting the stage for how future conditions may impact the Lake Erie basin and what we, as the Lake Erie resident population, will have to do to adjust to those changes. Referring back to Figure 2.2 in Section 2, the issues of concern in Lake Erie will continue to change over time. This section keeps the door open to new issues and encourages research and management approaches to be flexible.

11.2 Non-indigenous Invasive Species in Lake Erie

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Introduction

Non-indigenous invasive species (NIS) are successfully reproducing organisms transported by humans into an area outside their historic or geographic range including both foreign (i.e. exotic) and transplanted (i.e. outside its native geographic range but within the country where it naturally occurs) (Fuller *et al.*, 1999). The risk of NIS is that they may lead to catastrophic changes in the existing natural community composition and the extinction of native species, resulting in the overall decline in biodiversity of aquatic (Mills *et al.*, 1993) and terrestrial (Heywood, 1989) communities. Introduced species, free from constraints of their home regions, can lead to the extinction of native species through predation, competition, modifications in habitat, and inhibition of reproduction (Elton, 1958; Moyle *et al.*, 1986). If a single species dominates an area, the value of the habitat is reduced.

Although some terrestrial introductions may be viewed as providing economic benefit to humans (crops, horticulture, game species), aquatic introductions have been a "mixed blessing" (Fuller *et al.*, 1999). About 15% of all NIS taxa in the U.S. cause "severe harm" (United States Congress 1993). Mills *et al.* (1993) estimated that about 10% of these NIS taxa (21% invertebrates and diseases, 20% fish, and 5% algae and aquatic plants) are considered to be harmful to ecosystem health in the Great Lakes. The apparent lack of effect of most NIS does not mean that there has been no effect from these species, but that they have not been well studied.

There are over 50,000 NIS in the United States. Even if only a fraction of the total number of invaders is harmful, this represents significant damage to natural and managed ecosystems and public health (Pimentel *et al.*, 2000). A recent estimate of damage and control of the zebra mussel alone is $100 million (U.S.) per year (Charles R. O'Neill, New York Sea Grant, cited in Pimentel *et al.*, 2000). Pimentel *et al.* (2000) estimate that the economic damages associated with NIS effects and their control amount to approximately $137 billion (U.S.) per year. The challenge, however, is not to determine exact costs of invading species impacts, but to prevent additional damage to natural and managed ecosystems caused by NIS (Pimentel *et al.*, 2000).

Lake Erie, from the shallow, nutrient-rich, historically productive western basin to the progressively deeper and less productive central and eastern basins, provides numerous habitat, temperature and trophic gradients that are reflected in the diversity of native and non-native communities among the three basins (Edwards and Ryder, 1990). The major changes in Lake Erie over the years have been attributed to the introduction of NIS, habitat destruction, commercial overfishing and fluctuating levels of nutrient enrichment (Leach, 1995).

Vectors

The Laurentian Great Lakes are particularly susceptible to invading species owing to the presence of canals and international ship traffic. The historic canal era in the early 1800s connected Lake Erie to waters outside of the Lake Erie drainage basin (i.e. Erie Canal, Miami Canal), and the Welland Canal, opened in 1829, allowed invaders, such as sea lamprey and alewife, to move upstream from Lake Ontario. The opening of the St. Lawrence Seaway in 1959 enhanced the migration of species into Lake Erie as "hitchhikers" in the ballast water of foreign ships. The rate of invasion has increased dramatically since the opening of the Seaway. Different taxonomic groups are associated with the type of ballast discharged by ships. Before 1900, plants (seeds), molluscs and insects were predominately transported in mud or rock used for ballast. Later, fish, invertebrates and plankton were transported in liquid ballast. Other mechanisms by which exotics entered the Great Lakes include intentional management decisions, release/escape of ornamental species, bait-bucket transfer, and fouling from shipping activities and other transportation routes.

Ballast discharged from ships that took on water from foreign ports has been the pathway for many invading species including zebra mussels *(Dreissena polymorpha)* and the round goby fish (*Neogobius melanostomus).* The mandatory ballast water exchange program under the U.S. Non-indigenous Aquatic Nuisance Species Prevention and Control Act of 1990 did not take effect until 1993 (Leach *et al.*, 1999). Similar laws have not been enacted in Canada. Although vessels entering the Great Lakes must have exchanged ballast water in mid-ocean and arrive with salinity concentrations in excess of 30 ppt, brackish water species (including algae and crustaceans) may survive ballast exchange. Additional ballast water treatment is needed to prevent future invaders from entering the Great Lakes or from intrabasin transfer among port harbors.

Invaders

It should be noted that the invasion of NIS is a dynamic process with "new species" being found with regularity, particularly among the plant community.

Plants

The Invasive Plants of Canada (IPCAN) monitoring project, developed by the Canadian Wildlife Service as part of the Biodiversity Mapping Program (BIOMAP), was established for documenting the biology, range and control of invasive plants and for computer mapping of NIS harmful plants (http://infoweb.magi.com/~ehaber/ipcan.html). In the U.S., the University of Florida Center for Aquatic and Invasive Plants has similar resources for documenting NIS plants (http://aquat1.ifas.ufl.edu/).

Two species of red algae *(Bangia atropurpurea* and *Chroodactylon ramosum),* native to the Atlantic coast and presumed to have entered Lake Erie in ship ballast, are common along shorelines. Green algae *(Enteromorpha prolifera* and *Nitellopsis obtusa)* that occur in Lake St. Clair and the St. Clair and Detroit connecting channels have been observed flowing into Lake Erie (Manny *et al.*, 1991; Mills *et al.*, 1993). It is a challenge to detect established populations of small organisms; however, several species of invasive diatoms have been reported in Lake Erie (Mills *et al.*, 1993). One species, *Stephanodiscus binderanus,* causes water quality problems in sewage treatment facilities (Stoermer and Yang, 1969).

Lake Erie has many invasive submerged, emergent and terrestrial plants. Examples of submerged invasive plants are European water clover *(Marsilea quadrifolia)*, water cress *(Rorippa nasturtium aquaticum)*, Eurasian watermilfoil *(Myriophyllum spicatum)*, curly pondweed *(Potamogeton crispus)*, spiny naiad *(Najas marina)*, and minor naiad *(Najas minor)* (Stuckey 1979, 1985; Mills *et al.*, 1993). Common invasive plants of Lake Erie wetlands include: bristly lady's thumb *(Polygonum caespitosum* var. *longisetum);* bitterdock *(Rumex obtusifolius);* poison hemlock *(Conium maculatum);* bittersweet nightshade *(Solanum dulcamara);* western water horehound *(Lycopus asper);* mint *(Mentha* spp.*);* smooth field sow thistle *(Sonchus arvensis* var. *glabrescens);* flowering rush *(Butomus umbellatus);* the narrow leaved cattail *(Typha angustifolia);* and grasses *(Alopecurus geniculatus, Echinochloa crusgalli, Poa trivalis)* (Stuckey 1968, 1969, 1985, 1987, 1988; Aiken *et al.*, 1979; Mills *et al.*, 1993).

Garlic mustard *(Alliaria petiolata)* is one of the most rapidly expanding NIS of woodland habitats in North America. It forms such dense monocultures that many native plants, such as the endangered wood poppy, *Stylophorum diphyllum*, and the threatened white wood aster, *Aster divaricatus*, have disappeared from areas into which it has spread (White *et al.*, 1993). Garlic mustard plants produce thousands of seeds that scatter several feet from the parent plant. The extended period of germination makes it especially difficult to eradicate.

Purple loosestrife, a tall perennial herb, spreads aggressively by underground rhizomes and can produce over 2.5 million seeds per plant per year. It has formed dense monocultures in Lake Erie wetlands that are impenetrable by birds and wildlife seeking shelter or escape. The spread of purple loosestrife is particularly troublesome because the plant cannot be used effectively as a food source by native wildlife. Migratory and breeding use of the affected wetlands is also impaired. The tall feathery *Phragmites* is another plant that has been invading wetlands and roadside ditches. It also eliminates many native plants and creates monocultures of low food value. The jury is still out regarding whether this species is native or a NIS strain (J. Robinson, pers. comm.).

Eurasian watermilfoil can form large floating mats of vegetation that impede navigation nearshore and prevent light penetration for native submerged macrophytes (Mills *et al.*, 1993). It has a much lower food value for waterfowl compared to native plants. Large decaying mats washed to shore create conditions conducive to botulism outbreaks in waterfowl and shorebirds. Eurasian watermilfoil is considered to be the cause of the current degraded state of Rondeau Bay in Ontario. The native submergent plant community was displaced by milfoil in the 1960s with the milfoil dying out in 1977 for unknown reasons. This left the bottom sediments bare and unprotected by rooted aquatic plants. The subsequent sediment resuspension in the water column made the water too turbid to allow significant re-growth of native aquatic plants in the bay. This habitat alteration resulted in the loss of the warmwater fishery and use by waterfowl (J. Robinson, pers. comm.). Various management actions have since been implemented to try to restore the bay.

Invertebrates

Several species of crustaceans have invaded Lake Erie including the cladocerans *Bythotrephes cederstroemi* (now *Bythotrephes longimanus), Bosmina (Eubosmina) coregoni* and *Bosmina (E.) maritima*, and the amphipod *Echinogammarus ischnus* (Mills *et al.*, 1993; Witt *et al.*,1997). The amphipod, *E. ischnus*, was first observed in Lake Erie in 1995 and has since expanded in abundance and distribution (Witt *et al.*, 1997). The *Bosmina* species are benign invaders (De Melo and Hebert, 1994). However, *Bythotrephes longimanus* (formerly known as *Bythotrephes cederstroemi*, or “B.c.,” the “spiny water flea”) is a cladoceran with a long, sharp, barbed tail spine that feeds on native zooplankton (MacIsaac *et al.*, 2000). The spiny water flea likely competes with fishes (especially young-of-the-year yellow perch) for zooplankton. Because the barbed spine affords the organism protection from fish predators, *Bythotrephes* has flourished.

Of the 15 species of crayfish in the Lake Erie basin, two species, *Procambarus (Scapulicambarus) clarkii* and *Orconectes (Procericambarus) rusticus*, are NIS (R. Thoma, pers. comm.). *Procambarus clarkii* was accidentally introduced into the Sandusky Bay and Grand River areas of Ohio and may affect native crayfish populations of *P. acutus.* There is evidence that the rusty crayfish, *O. rusticus*, invaded Lake Erie through the Miami Canal which was constructed between the years of 1825 and 1847 to join the Miami River (its native range) to the Maumee River (R. Thoma, pers. comm.). The large, aggressive rusty crayfish may displace native crayfish *(O. virilis* and *O. propinguus)*, and substantially reduce aquatic plants which are important habitat for invertebrates and fishes (Olsen *et al.*, 1991) and which reduce erosion by stabilizing the sediments and minimizing wave action (Gunderson, 1995).

Numerous molluscan species have invaded Lake Erie, but many species of gastropods (snails) *(Bythinia tentaculata, Radix auricularia, Valvata piscinalis)*, sphaeriids *(Pisidium amnicum, P. supinum, Sphaerium corneum)* and the corbiculid *Corbicula* *fluminea* have not had detrimental effects on the Lake Erie community (McMahon, 1983; Mackie, 1996). McMahon (1983) suggested that the Asian clam, *Corbicula fluminea*, would unlikely be a pest in Great Lakes waters because the clam cannot tolerate cold water temperatures in winter.

The first records of the zebra mussel, *Dreissena polymorpha*, and quagga mussel, *D. bugensis*, in Lake Erie are 1988 and 1989, respectively. Dreissenids form colonies on both hard and soft bottom substrates. Quagga mussels dominate the colder deeper eastern basin of Lake Erie, but have recently colonized the western basin (Mills *et al.*, 1999). These NIS molluscs have had the most dramatic ecological and economic influence on the Lake Erie ecosystem. Dreissenids have been implicated in the reduction of lake productivity (Dahl *et al.*, 1995) and change in contaminant dynamics within the lake (Morrison *et al.*, 1995). Makarewicz *et al.*, (1999) concluded that there were significant reductions in select divisions of phytoplankton (e.g. Chlorophyta, Bacillariophyta, Cyanobacteria) in the western basin of Lake Erie, but the effect of dreissenids on the phytoplankton community in the central and eastern basins has been minimal. Zebra mussels have eliminated most native unionids (mussels) through their biofouling habits (Schloesser *et al.*, 1996). Dermott and Munawar (1993) demonstrated that the amphipod, *Diporeia hoyi* (a dominant prey of smelt which is itself an exotic) has declined dramatically because of competition with *D. bugensis.* In contrast, other species have increased owing to enhanced food (i.e. pseudofaeces) or habitat complexity provided by dreissenids (Dahl *et al.*, 1995; Steward *et al.*, 1998).

The filter-feeding capacity of dreissenids has created another complication in the Lake Erie ecosystem. Contaminants in the water, sediment and organisms ingested by the mussels accumulate rapidly in zebra mussels. This creates a link that increases biomagnification up through the food chain. Ohio Sea Grant-funded research being conducted by Fisher and Baumann (Jentes, 1999) shows a connection from zebra mussels to round gobies to smallmouth bass. After eating contaminated sediments and algae, PCB concentrations in zebra mussels were approximately 100 ppb. PCB concentrations in round gobies, another NIS that feeds on zebra mussels, were found to range from 200 to 800 ppb. PCB concentrations in smallmouth bass, a Lake Erie fish that has become a predator of gobies, ranged from 1,100 to1,800 ppb. This new situation could have dire consequences for the rest of the Lake Erie fauna and humans.

From an economic perspective, zebra mussels have coated and clogged many water intake pipes for drinking and cooling water drawn from Lake Erie. Millions of dollars have been spent to clean pipes and install treatment systems to prevent zebra mussels from attaching to intake pipes or being drawn in further to foul the water treatment and distribution systems.

Fish

There are 143 fish species in the Lake Erie basin (USFWS 1995) and 95 species in the lake proper (Cudmore, 1999). Within Lake Erie, there are 34 NIS, 19 of which are established and 15 others that have been reported. Ten fish species have been extirpated from Lake Erie and one subspecies, blue pike *(Stizostedion vitreum glaucum)*, is extinct (Corkum *et al.*, 2000). Introduced fishes (e.g. rainbow smelt, white perch) have represented part of the commercial fishery and, since 1950, NIS species have represented a major part of the harvest.

As an example of the impacts invasive fish species are having on the lake, there have been changing patterns of trophic guilds between commercial landings of native and NIS species from Lake Erie in the last century (Corkum *et al.,* 2000). From 1900 to 1950, piscivores, planktivores, and to a lesser extent omnivores comprised native landings. Benthivores were present in very low numbers. The NIS landed species were benthivores (carp and goldfish). From 1950 to the present, NIS represented the major component of the fish harvest. Omnivores and piscivores now dominate native landings. Planktivores (rainbow smelt) dominate the NIS catch, with benthivores and omnivores also very common (Corkum *et al.,* 2000).

Some of these changes in feeding guilds resulted from a combination of species invasions, reductions in nutrient concentrations in Lake Erie, and changes in the commercial fishery (e.g. "fishing up" the food chain) (Regier and Loftus, 1972). "Fishing up" describes the process where there is a shift in fishing effort from higher to lower valued fishes as preferred species decline in abundance. Overfishing reduced lake herring, a native planktivore; however, the presence of NIS rainbow smelt and alewife, which feed on larval fish, kept lake herring from recovering (Ryan *et al.*, 1999). The increasing rainbow smelt population fueled a new commercial fishing interest, particularly in the eastern basin. However, that fishery is now collapsing as the burrowing amphipod *Diporeia*, a food source to smelt, has declined from 38% to 1.8% of the biomass in the eastern basin since the advent of dreissenids (Dermott and Kerec, 1997). Thus, NIS can disrupt the functioning of the ecosystem and the passage of energy up the food chain and impair the aquatic community (Johannsson and Millard, 1998).

There is strong evidence that a diet dominated by smelt and alewife results in a thiamine deficiency in lake trout causing a reproductive impairment called early mortality syndrome (EMS). Should this dietary linkage prove correct, full restoration of lake trout in Lake Erie is unlikely as smelt now constitute the major part of the diet (Fitzsimons and Brown, 1998). The EMS problem is unfolding as one of the more insidious impacts of NIS in the Great Lakes.

Because of the lack of spawning and nursery habitats in stream riffle areas with clean sand and gravel, the earliest invasions of sea lamprey did not proliferate in Lake Erie as it did in the other Great Lakes (Trautman, 1981; Leach, 1995). Populations of sea lamprey increased to the point that they were sufficiently abundant to impact populations of lake trout, particularly in the eastern basin, and may have prevented the success of lake trout restoration efforts. Control efforts (1986-1987, 1990, 1994) on New York tributaries of Lake Erie for sea lamprey were successful in reducing the population, enabling lake trout to increase after 1992 (Culligan *et al.*, 1999). Cornelius *et al.* (1995) demonstrated the dramatic improvement in survival of lake trout following these stream treatments. This increase in survival was essential in establishing the stock of mature lake trout that exist today at an abundance sufficient to effectively reproduce in the lake. Nevertheless, sea lamprey continue to parasitize older lake trout. In 1998, the attack rate by sea lamprey on lake trout was 34 wounds per 100 lake trout (>532 mm), representing a five-fold increase from 1991. Accordingly, the Lake Erie Committee (of the Great Lakes Fishery Commission) recommended that increased control efforts be applied to Lake Erie tributaries where sea lamprey spawn and ammocoetes develop (Culligan *et al.*, 1999).

Two bottom-dwelling fishes, the round goby, *Neogobius melanostomus*, and tubenose goby, *Proterorhinus marmoratus*, entered Lake Erie in 1993 and 1996, respectively. The more aggressive round goby now occurs in all of the Great Lakes. Reasons for proliferation of round gobies include their tolerance of a wide range of environmental conditions, a broad diet that includes dreissenids (Ray and Corkum, 1997), aggressive behaviour, an ability to spawn repeatedly, parental care by males to facilitate successful recruitment, and a large body size compared with species of a similar benthic lifestyle (Charlebois *et al.*, 1997). Concerns about the round goby include their ability to transfer contaminants through the food web, their effect on native species (Jude *et al.*, 1995; Dubs and Corkum, 1996), and their ability to proliferate owing to their multiple spawning habits (Corkum *et al.*, 1998; Wickett and Corkum, 1998). The round goby has become an important prey of smallmouth bass and also contributes to the diet of yellow perch, walleye, burbot and other fishes (Lake Erie Forage Task Group, 1999).

In 1997, the rudd, *Scardinius erythrophthalmus*, a large, deep-bodied minnow with blood-red fins, native to western Europe and the Ponto-Caspian (Fuller *et al.*, 1999) was reported in eastern Lake Erie at Crystal Beach (Ontario MNR, 1998). The effects of rudd on native species are unknown, but they may hybridize with the native golden shiner, an important bait fish species.

One of the most destructive NIS fish species is the common carp, *Cyprinus carpio.* It was introduced to the Great Lakes by a government stocking program in 1879 (Trautman, 1981). Carp proliferated, hybridized abundantly with goldfish, and became a major component of the Lake Erie commercial fishery, particularly in the western basin. They have caused much habitat destruction in nearshore areas and wetlands, digging up vegetation and increasing turbidity with their aggressive mating habits.

Future Invaders

Characteristics of successful invaders include high fecundity, rapid dispersal mechanisms, wide tolerance of environmental factors, and access to climatically matched habitats through pathways or corridors (Lodge, 1993). Rarely have ecologists been able to predict the success of colonizers, yet statistical regularities are known about the proportions of successful invaders (Williamson and Fitter, 1996). Ecologists can develop a list of potential invaders by examining comparable characteristics of invading species (Lodge, 1993; Mills *et al.*, 1994; Leach, 1995), donor and recipient habitats and climates, vulnerability of recipient communities such as disturbance (Lozon and MacIsaac, 1997), and international trade routes and dispersal mechanisms (Carlton 1985; Williams *et al.*, 1998).

Despite the mandatory ballast water exchange program, NIS will continue to enter Lake Erie (Locke *et al.*, 1993). It is virtually impossible to eliminate organisms from the bottom sludge in ballast tanks of ships without treatment (Leach *et al.*, 1999). Accordingly, future NIS will most likely be those estuarine species from foreign ports that can tolerate fresh water (Witt *et al.*, 1997). Future invaders into Lake Erie will also come from nearby drainages. Future alterations in the thermal regime and ice cover of the lake related to climate change could also affect habitat and the ability of NIS to become established in the basin.

Attention must be given to the impacts of NIS in the Lake Erie drainage basin as a whole. Insect pests and diseases can devastate the remaining forests in the basin, altering land cover and influencing runoff to Lake Erie as well as destroying habitat. Dutch elm disease and chestnut blight affected many of the basin forest communities as well as city and suburban landscapes. Gypsy moths and Japanese long horn beetles are major NIS pests of concern. The introduction of NIS vertebrates can upset terrestrial communities as well as the aquatic communities that play a role in their food chain.

The European water chestnut, *Trapa natans*, is a significant nuisance aquatic weed that reproduces rapidly and forms extensive floating mats. It was likely spread through aquarium release or escaped from private ponds. *Trapa natans* occurs in the northeastern U.S. including New York (e.g. Sodus Bay on the south shore of Lake Ontario) and Pennsylvania (Groth *et al.*, 1996). The plant was reported in Canada in 1998 in southwestern Quebec in a tributary of the Richelieu River. Mechanical control methods have been used at Sodus Bay annually since the 1960s (Mills *et al.*, 1993), but the plant persists. Hydrilla *(Hydrilla verticillata)* is another nuisance aquatic weed likely spread through aquarium release or escaped from private ponds. It creates densely branched mats on the water surface. It has not entered the Great Lakes yet, but it is the most abundant aquatic weed in Florida and has spread up the east coast of the U.S. Once introduced, it has the potential to become prolific, especially in Lakes Ontario, Erie and St. Clair (Madsen, 2000, ANS Conference).

The zooplankton, *Daphnia lumholtzi*, native to eastern Australia, India, and east Africa, was reported in reservoirs in Missouri and Texas in the early 1990s (Havel and Herbert, 1993; Havel *et al.*, 1995). The long spined (helmet and tail) zooplankton has expanded its distribution throughout the U.S. and is now in reservoirs in Michigan and Ohio (D. Culver, pers. comm.). Because *D. lumholtzi* prefers warm waters, the species will likely invade the shallow western basin of Lake Erie. The spiny zooplankton has an advantage over other zooplankton in obtaining food resources and in deterring predators.

Cercopagis pengoi, a predatory crustacean with a long barbed tail, was reported from Lake Ontario in 1998 (MacIsaac *et al.*, 1999). Although the effects of *Cercopagis* are unknown, it is likely that the crustacean will exert predation pressure on smaller cladocerans and may compete with young-of-the-year fishes for zooplankton. Given the transportation links between Lakes Ontario and Erie, this exotic species will soon enter Lake Erie.

Potamopyrgus antipodarum, the New Zealand mudsnail, has been documented along the southern and eastern shores of Lake Ontario (Zaranko *et al.*, 1997). Densities of *P. antipodarum* are up to 5,650 snails/m^2 in Lake Ontario; these densities are substantially lower than other records of the mudsnail invasion in western U.S. (up to 10^5 snails/ m^2) (Bowler, 1990; Zaranko *et al.*, 1997). Bowler (1990) anticipates the high densities of the

New Zealand mudsnail will adversely affect native snails.

It is likely that three fishes (blueback herring, *Alosa aestivalis*; fourspine stickleback, *Apeltes quadracus*; and ruffe, *Gymnocephalus cernuus*) will enter Lake Erie within the next five years. The blueback herring was first reported in Lake Ontario near Oswego in 1995 (Owens *et al.*, 1998). This marine fish, a pelagic planktivore and a relative of the alewife (*Alosa pseudoharengus*), likely entered the lake from the Erie Barge Canal that links the Hudson River drainage and Lake Ontario. This species is even more sensitive to cold temperatures than is the alewife, and the thermal regime of Lake Erie may not provide a suitable habitat for it to become established (R. Lange, pers. comm).

The fourspine stickleback is native to the Atlantic coast and now occurs in the Hudson River and Susquehanna River drainage of Pennsylvania (Fuller *et al.*, 1999). It is likely that the fourspine stickleback could enter Lake Erie. Although the potential effects of this invader are unknown, the fourspine stickleback may feed on eggs of other native fishes.

The bottom-dwelling ruffe was introduced into Lake Superior by ship ballast and presumably spread within the basin by intralake shipping (Stepien *et al.*, 1998). It was first collected in the St. Louis River, Duluth, in 1986, and subsequently dispersed along the south shore of Lake Superior and to Alpena, Lake Huron (Fuller *et al.*, 1999). Competition between ruffe and perch is likely because they consume the same food and because ruffe are generalists in habitat use (Ogle, 1995; Ogle *et al.*, 1995). Thus, when ruffe arrive in Lake Erie, it may adversely affect yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*), valuable commercial and sport fishes.

A concern greater than tallying new species that enter Lake Erie is to determine the effect of NIS on native species. Of all the recent changes in Lake Erie, it is likely that the round goby will be influential in transferring energy from the lake bottom up through the food chain. In 1999, the round goby was reported in commercial catches from the western and central basins (T. Johnson, pers. comm.) and their numbers in agency gillnet surveys have increased substantially since their first appearance in Lake Erie in 1993 (Lake Erie Forage Task Group, 1999). The round goby may affect other fishes by interfering with their reproductive behaviours. Also, the round goby has been reported to feed on eggs of lake trout (Chotkowski and Marsden, 1999) and lake sturgeon (Nichols *et al.*, 1999). Just as zebra mussels were responsible for transferring energy from the pelagic zone to the benthos (Leach, 1995) round gobies are positioned to reset the system by transfering energy and contaminants from the benthos into organisms that dwell in the water column. Overall, the round goby will impact the community structure of Lake Erie.

The effect of invasive species on the Great Lakes ecosystem is a complex problem that cannot be resolved by funding studies one species at a time. One solution is for governments to fund long-term studies that examine the effect of multi-species invaders on food web dynamics.

Clearly, the invasion of organisms into new areas results in economically and environmental devastating consequences (Kareiva, 1996). A special feature of the 1996 issue of the journal, *Ecology*, challenged researchers to make invasion ecology a predictive science. Ecologists still do not know why some invaders are so damaging (e.g. sea lamprey and zebra mussels) and the effects of others are negligible. Large sums of money are spent on the control of *exotics* through programs such as the Great Lakes Fishery Commission. Recently, the United States Congress allocated one million dollars for “the Chicago Barrier,” a project to install an electric fence on the Chicago Sanitary and Ship Canal. This electric barrier is designed to prevent the exchange of exotics between the Great Lakes and Mississippi Drainage basins. However, an inadvertent bait bucket transfer of a NIS could easily eliminate any anticipated benefit of a barrier.

Kareiva (1966) argues that the most striking feature of studies on species invasions is “the absence of manipulative experiments in the tradition of modern community ecology.” Large scale, multi-species, manipulative experiments have been underexploited owing to the absence of funds for long term ecological studies that focus on food web dynamics. Granting periods are typically one to two years and often focus on three species or less. Unless agency and institutional partnerships are funded for the long term (10 years or more), resource management of Lake Erie and other Great Lakes is futile.

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11.3 Climate Change

Scientists have known for over a century that gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide produce a *greenhouse effect* by allowing short wave solar radiation to enter the atmosphere, while at the same time preventing long wave terrestrial radiation to pass back out. This is a natural and beneficial process, without which Earth would be a frozen and lifeless planet. Scientists are concerned, however, that human activities, such as the burning of fossil fuels and the destruction of tropical rain forests, are elevating the concentrations of greenhouse gases to the point where they could have a dangerously disruptive effect on the atmosphere by producing an artificially *enhanced greenhouse effect*.

For most of history, human sources of greenhouse gases have had a negligible effect on the atmosphere. However, with the beginning of the Industrial Revolution, concentrations of carbon dioxide, methane, and nitrous oxide have increased by 30 percent, 145 percent, and 15 percent, respectively. Scientific experiments with computer models of the atmosphere have shown that these increases are sufficient to have induced a rise in global mean temperature of 0.4 to 1.3 C. This warming has been confirmed, moreover, by measurements, which have shown that over the last century, average temperatures have increased by 0.5 C globally, 1.0 C nationally, and 0.6 C in the Great Lakes-St. Lawrence Basin (Southam *et al.*, 1997). There is now a general consensus in the scientific community that anthropogenic activities have significantly increased the atmospheric concentrations of CO_2 and other greenhouse gases, and that this has produced a discernible influence on global climate. It is expected that there will a doubling of carbon dioxide concentrations in the atmosphere in the 21st century, with a corresponding increase in average global temperatures of one to four degrees C (Intergovernmental Panel on Climate Change, 1996).

Based on projections using several state-of-the-art models (Mortsch and Quinn, 1996; Croley, 1991), experts from the U.S. National Oceanic and Atmospheric Administration (NOAA) and Environment Canada believe that global warming could result in a lowering of lake levels by a meter or more by the middle of the 21st century. This development would cause social, economic and environmental impacts throughout the Great Lakes region (IJC, 2000). The results of the models predict the same general results, but to varying degrees. Air temperature, overall precipitation, evapotranspiration, runoff, and lake surface water temperatures will increase. Total basin moisture, snow, soil moisture, groundwater levels, lake levels and percent ice cover are predicted to decrease.

In addition to changes in the type of precipitation, there will be an increase in precipitation variability and intensity caused by the greater frequency of intense cyclones, and the reduction of mild ones. The effect of this, coupled with increased evapotranspiration, will be a corresponding increase in both the frequency and severity of floods (IPCC, 1996) and droughts.

A water quality model for Lake Erie, developed by Lam *et al.* (1987), although designed for current climatic conditions, indicates that global warming can impact significantly on nutrient and dissolved oxygen concentrations. Statistical calculations for the central basin of Lake Erie show a definite correlation between anoxia occurrence and climate-induced changes in the thermal characteristics of the lake. Another study by Blumberg and DiToro (1990), that examined the effect of a doubling of CO_2 scenario on the dissolved oxygen levels in Lake Erie, found that losses of 1.0 mg/L in upper layers and 1.0-2.0 mg/L in the lower layers can be expected, as can an increase in the area of the lake that is anoxic. For shallow lakes, such as Lake Erie, changes in water levels can also affect oxygen levels by altering the dynamics of the mixing processes (Arnell *et al.*, 1996). Added to this is the possibility that buoyancy driven turnovers will be less frequent or may not even occur in some years, as previously discussed. Considering these factors, Hofmann *et al.* (1998) hypothesize that "the water quality (nutrient and dissolved oxygen distributions) may be adversely affected. Increased temperature, changed nutrient and oxygen conditions are expected to impact on ecosystem components such as fisheries habitat and health."

Of particular concern are the predictions of poorer water quality and shifts in species composition. Increases in fish yields (warm water species) will be concurrent with eutrophic-like conditions and increased contaminant loading and bioavailability. While a warmer climate will provide longer seasons for agriculture and commercial shipping, changes in seasonal runoff patterns, decreases in total basin moisture and lake level decline will have negative consequences. Lake level decline will also result in significant loss, migration and changes in wetlands. Most impact assessment efforts have been concentrated on physical responses. The biological consequences of the physical responses to climate change have yet to be seriously explored.

It should not be assumed that climate change impacts on the Great Lakes basin ecosystem will take place only gradually over the next several decades. Human-induced climate change will be superimposed on normal climate variability and natural events, intensifying storm events or climate conditions. Due to the predicted impacts of climate changes on lake levels, it is suggested that considerable caution be exercised with respect to any factors potentially reducing water levels and outflows (IJC, 2000).

The Lake Erie LaMP decided early in the development process that addressing the issue of water levels in Lake Erie was beyond the scope of the LaMP and was being addressed under other venues. However, the Lake Erie LaMP may to need to further discuss this issue from the perspective of linking lake levels to climate change and all the other potential impacts that climate change could have on the entire lake ecosystem.

As part of its Great Lakes St. Lawrence Basin (GLSLB) Project, Environment Canada has developed future scenarios for the Great Lakes region based on predicted climate changes and physical conditions. A report that examines in detail these scenarios and the potential impact they would have on the communities and ecosystems in and around Lakes Erie and Ontario is in preparation (Jessup, in prep.). A summary of Jessup's report has been drafted by Environment Canada to use as an issue paper to initiate discussion for LaMP 2002.

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11.4 Endocrine Disruption

Overview

The endocrine system is responsible for regulating and maintaining biological functions that are critical for normal growth, development and reproduction. It includes the brain, reproductive organs, and various endocrine glands. Endocrine glands regulate biological processes through chemicals called hormones (e.g. estrogen, testosterone, and thyroxine), that provide a means of communication between glands and tissues. These chemical messengers act on specific locations in the body, called receptor sites, where they deliver their messages. The action of natural hormones binding to their specific receptor sites is a crucial step in the endocrine system's normal operations, and interference with this process can have profound effects on an organism's behavior and physiology. Moreover, the immune and nervous systems interact closely with the endocrine system, and any one of these systems can influence the others.

Recently, government, industry, and environmental groups are attempting to learn more about the environmental endocrine issue. Some man-made chemicals (e.g. certain pesticides, plastics, detergent ingredients, and food products) have the potential to interact with the endocrine system of humans and wildlife. Such chemicals are called ***endocrine modulators*** or, as often described in the media, ***endocrine disruptors***.

Endocrine disruption by exogenic (originating externally) chemicals is not a new concept. Scientists generally agree that some chemicals could interfere with the endocrine system at high doses. For example, birth control pills, and some pesticides, such as DDT and toxaphene, now banned from use, are endocrine disruptors by design. The main question to be answered most recently is whether the health of humans and wildlife around the world is being adversely affected by the presence of *small amounts* of many different types of man-made chemicals in air, water, and food. With this and many other questions still unanswered, the potential risk associated with endocrine disruption by contaminants in the environment has become an intensely debated issue.

The Center for the Study of Environmental Endocrine Effects maintains a website with information on current developments as well as a bibliography of additional references. The Internet address is http://www.endocrine.org. U.S. EPA also maintains a website that provides details on the EPA Endocrine Disruptor Screening Program and links to other relevant websites. The Internet address is http://www.epa.gov/scipoly/oscpendo/.

Endocrine Disruption

Endocrine disrupting chemicals work through several mechanisms, usually by either mimicking natural hormones, blocking receptor sites, or by delivering the inappropriate message. Reports describing endocrine-related ailments in both human and wildlife populations are emerging. Some of the more notable human physiological concerns are increases in reproductive tract cancers and abnormal sexual development. While several studies assert that there is a downward trend in male sperm counts, this is still an ongoing debate within the scientific community. Some of the more documented observations in wildlife populations are decreasing hatching success in birds, alligators, and turtles, the synthesis and secretion of a female hormone by male fish, changes in immune response, and behavioral modification. While there is disagreement among scientists on the cause and extent of the issue, there is a consensus that environmental endocrine disruption is a potential risk requiring immediate attention.

Some of the chemical classes that are receiving significant endocrine-related publicity are alkylphenols, carboxylate derivatives, and dioxins, which are found in many consumer products and industrial wastes. Also receiving attention are certain pesticides and medicinal products. Many of these chemicals are pervasive in our environment and human exposure occurs through several pathways, including inhalation, digestion, and dermal contact. Similar routes of exposure occur in wildlife. While many specific chemicals are labeled suspect, significant questions remain about their potency and efficacy to act as endocrine disruptors at environmental concentrations. Therefore, three major questions that still need to be answered are:1) what chemicals still need to be added to the list of those classified as endocrine disruptors; 2) how serious of a risk to humans and wildlife are endocrine disruptors at ambient environmental concentrations (in particular what is the actual level of exposure from all sources, including dietary intake); and 3) how widespread in the environment are endocrine disrupting chemicals?

Current Research Efforts

Evaluation of risk associated with hormonally active chemicals in the environment is based on: a) *hazard*- the harmful effect that a chemical might have on the body even if it only happens at exposure levels that are unrealistic or never encountered in real life; b) *potency*- measures how little of a substance is needed to cause a particular effect; and c) *exposure*- the amount of chemical that comes into contact with the body.

There are currently efforts underway to address these issues and the above-mentioned questions by the U.S. National Academy of Sciences, the U.S. EPA Risk Assessment Forum, and researchers at both Health Canada and Environment Canada. The Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) is an advisory committee called together by U.S. EPA to provide guidelines for developing a screening and testing program for suspected endocrine disrupting chemicals. Under this strategy, further testing would be performed on those chemicals with significant endocrine disrupting potential. In Canada, Health Canada participates in the international Organisation for Economic Cooperation and Development (OECD) to develop regulatory chemical testing protocols on endocrine disruptors. Both Health Canada and Environment Canada researchers are testing the efficiency of procedures to identify endocrine disruptors and are studying the toxic potential of these, and other chemicals. For example, through epidemiological and laboratory research Health Canada assesses the potential for these chemicals to induce reproductive or neurological dysfunction and breast or prostrate cancers.

Great Lakes

The Canadian government has invested $40 million in the Toxic Substance Research Initiative which supports a large number of collaborative research projects between government and university laboratories to address the endocrine disruptor issue in the Great Lakes basin.

To evaluate the potential for widespread endocrine disruptor effects in fish, U.S. EPA Region 5 initiated a program to assess whether endocrine disruptors may be adversely affecting fish populations in tributaries, harbors, and open waters of Lakes Superior, Michigan, and Erie. This effort is focused on chemicals that have only recently been shown to be endocrine disruptors to fish rather than evaluating endocrine disrupting chemicals such as PCBs and dioxins, which have already received considerable attention. Specifically, an effluent screening study funded by Region 5 and conducted by USGS at several large wastewater treatment plants in the Region was published in 1999. Survey results showed that degradation products of alkylphenol polyethoxylate nonionic surfactants (APEs) were present in the effluents at concentrations significantly higher than endocrine effect levels reported in the literature. This study is continuing and will analyze effluent, influent, and sludge samples at wastewater treatment plants in the following proposed locations: Duluth, Green Bay, Milwaukee, Akron (Cuyahoga River) and Detroit. Special emphasis is being placed on quantifying human hormone concentrations in these effluents, in addition to APEs. This study will also undertake a toxicity identification evaluation to determine the major chemicals and hormones responsible for fish endocrine disruption.

A second major study by the U.S. Department of Agriculture, funded by the U.S. Great Lakes National Program Office, can be characterized as a reconnaissance survey to assess whether there is potential for widespread endocrine disruption in Great Lakes tributaries and Lake Michigan, as typical of open water. This survey is evaluating known endocrine disruptor biomarkers to determine whether endocrine disruption may be occurring in fish populations in these locations. The study is also documenting concentrations of APE and a number of brominated flame retardants in fish tissue.

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11.5 Phosphorus Revisited

Phosphorus is an important nutrient that controls the amount of algae in the water column. Algae, or phytoplankton, are an important component of the aquatic foodweb. In the past, too much phosphorus resulted in too much algae which, when decayed, depleted the oxygen in the lake, creating *dead zones* where no organisms could survive. To alleviate the impacts of excessive phosphorus, a loading target of 11,000 metric tonnes/year was established under the Great Lakes Water Quality Agreement for Lake Erie. This target was reached by the late 1980s and has been fluctuating around this figure ever since.

Past and current phosphorus management practices have resulted in tremendous benefits to Lake Erie since their implementation in the 1970s. Reduced loadings of phosphorus have resulted in smaller quantities of algae and more oxygen in the system to support a healthier aquatic community.

In the 1990s, Lake Erie experienced profound ecological changes. These changes have raised concerns about the declining productivity in certain components of the aquatic ecosystem in Lake Erie. The most dramatic of these changes have been experienced in the eastern basin. In the 1970s, phosphorus had been deemed the culprit in making the lake too productive. Now that phosphorus loadings are under control, another factor has entered the equation, pushing productivity in the other direction. The invasion of zebra mussels is heavily implicated as that factor.

With the zebra mussel population explosion in Lake Erie, another organism that feeds on algae at the base of the food chain was added to the productivity equation. Zebra mussels' voracious feeding filtered suspended algae out of the water column. What was not used for maintenance and growth was expelled in little packets that sank to the bottom, resulting in fewer algae available to other organisms in the food web. Overall, the effect has been to change how efficiently energy is transferred and distributed in the aquatic foodweb.

While declining productivity is occurring in certain species throughout Lake Erie, some nearshore areas and tributaries continue to suffer from the impacts of nutrient enrichment (cultural eutrophication). These conditions also need to be considered in any evaluation of the role of phosphorus in the Lake Erie ecosystem.

Considering the many problems that arose from phosphorus over-enrichment of the lake during the 1960s and 1970s, and the uncertainties of the 1990s, the Lake Erie LaMP supports the position that phosphorus loadings to Lake Erie should continue to be limited to 11,000 metric tonnes per year. Future management decisions focused on the productivity of Lake Erie will need to be made based on overall foodweb dynamics and not just phosphorus management practices.

11.6 Other Emerging Issues

As the Lake Erie LaMP process progresses, it is likely that additional issues of concern will be reviewed for incorporation into the LaMP. Some of these issues may be beyond the scope the LaMP. If this is the case, the LaMP may still serve to educate stakeholders about these issues.

Long-Range Transport of Air Pollutants

One issue in particular that was not addressed in much detail in Lake Erie LaMP 2000 is that of the transport of air pollutants over long distances, and their subsequent deposition into Lake Erie. This phenomenon is also referred to as "long distance atmospheric transport", or "long-range transport" of air pollutants.

This is an issue important to all of the Great Lakes, but one that the Lake Erie LaMP has not yet explored in any detail. Much information is available for review to determine the importance of this issue to Lake Erie. That will be a task for LaMP 2002.